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Prof Toby Walsh

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Final Report for AOARD Grant: 124056 (12RSZ076) Lifelong Optimization

Peter Stuckey, Pascal Van Hentenryck, Toby Walsh

NICTA, Level 5, 13 Garden St, Eveleigh 2015, Australia
email: {peter.stuckey,pvh,toby.walsh}@nicta.com.au

Abstract

Optimisation solvers should learn to improve their performance over time. By learning both during the course of solving an optimisation problem as well as across multiple optimisation problems, we have demonstrated significant advances in the state of the art in scheduling, packing and related resource constrained combinatorial optimisation problems.

Introduction

Optimisation has traditionally been treated as a one-off task. In practice, optimisaiton is a lifelong process. Tomorrow's optimisation problem can be viewed in the context of todays and yesterday's. For example, we might want to optimise the schedule of activities today, but this is likely to be a similar problem to yesterdays, as well as to tomorrow's. In addition, we should view todays schedule in terms of the schedule for the whole week. For instance, if a particular worker was assigned to loading yesterday and today, we might prefer that they do so again tomorrow as they are likely to prefer such regularity and to be more effective. This grant set out to shift the prevailing paradigm of optimisation from an one-off task to one that is repeated and lifelong. There were two main goals: learning from past solving attempts and, as a necessary part of gaining trust over time and for learning from the past, developing methods to explain solutions. The benefits to the Department of Defence are to advance the state of the art in combinatorial optimization (for example, by closing open results in scheduling), and to develop new methods to deal with uncertainty and change.

Results

Lazy clause generation

Our major learning method is lazy clause generation, a novel combination of Constraint Programming (CP) and Learning. This has vastly improved the way that solvers infer and learn in combinatorial optimisation problems involving limited resources. The basic idea is very simple: dont repeat search mistakes by recording reasons from past failures. We have showed how we can reuse such learning across optimization problems [6]. By

closing numerous open problems, we demonstrated that such lazy clause generation improves the state of the art in solving difficult optimisation problems in two challenging benchmark domains: project and flexible job shop scheduling [10, 11]. We also looked at symmetry across optimisation problems [7, 1]. This work was recognized with the *Best Paper award* at the 18th International Conference on Principles and Practice of Constraint Programming.

Learning heuristics

To cope with dynamic, online optimisation problems with uncertainty, we developed some powerful and sophisticated techniques for learning heuristics, rules of thumb for making decisions [16]. We have recently started to apply this to an interesting pickup & delivery problem for collecting and delivering food donated to FoodBank Australia [14, 15].

Meta-optimisation

By formalizing aggregator constraints we developed a very general and useful class of meta-optimization problems called nested optimisation problems [8]. This permits us to specify and reason about optimisation problems involving uncertainty. Nested optimisation problems subsumes several existing classes including quantified Boolean formulae, multi-level stochastic optimization, and bi-level programming. By developing methods to explain propagation for this class we provide exponential reductions in search, and allow the direct specification of lifelong optimization problems as a single meta-optimisation problem.

RAAF prototype

Following a visit to Travis in August 2012, and discussions with TRANSCOM, we began a pilot project with the RAAF on solving their logistics problems. We have implemented a prototype solver and explored both constraint and mathematical programming approaches to the problem. The prototype works on an "australian-scale" problem with hundreds of requests to tens of locations. We are currently extending it to cope with crewing constraints, and to scale up to larger networks using automatic decomposition techniques. Our end goal is to productise this research so it can be fielded in the real world. Figure 1 gives a screenshot from the prototype in action.

Esteem measures

Peter Stuckey presented our work on lazy clause generation as a keynote talk at the 16th International Conference on Theory and Applications of Satisfiability Testing in August 2013 [12], at the 19th International Conference on Principles and Practice of Constraint Programming in September 2013 [13], and at the 15th International ACM Symposium on Principles and Practice of Declarative Programming in September 2013.

Toby Walsh presented the work on learning heuristics as the keynote talk at the 3rd International Workshop on Statistical Relational AI (held alongside the AAAI 2013

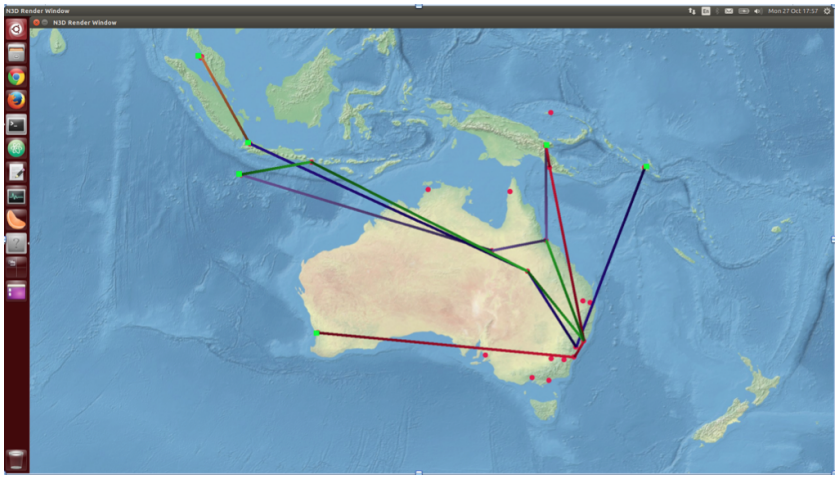

Fig. 1. Screen shot from RAAF prototype logistics decision support tool.

conference). He also presented the keynote at the 27th German Conference on Artificial Intelligence (KI-2014), and the 12th Foundations of Genetic Algorithms (FOGA 2013). He was awarded a prestigious Humboldt Research Award in 2014 in recognition of his ongoing contributions to the research field.

Publications associated with grant

Refereed journals

1. Geoffrey Chu, Maria Garcia de la Banda, Christopher Mears and Peter J. Stuckey. Symmetries, almost symmetries, and lazy clause generation. *Constraints*, 19(4):434-462, 2014.
2. Kathryn Glenn Francis and Peter J. Stuckey. Explaining circuit propagation. *Constraints*, 19(1):1–29, 2014.
3. T. Schrijvers, G. Tack, P. Wuille, H. Samulowitz, and P.J. Stuckey. Search combinators. *Constraints*, 18(2):269–305, 2013.
4. Andreas Schutt, Thibaut Feydy, Peter J. Stuckey, and Mark G. Wallace. Solving rcpsp/max by lazy clause generation. *J. Scheduling*, 16(3):273–289, 2013.

Refereed conference proceedings

5. Christian Bessiere, Emmanuel Hebrard, George Katsirelos, Zeynep Kiziltan, Nina Narodytska and Toby Walsh. Reasoning about Constraint Models. *Proceedings of 13th Pacific Rim International Conference on Artificial Intelligence (PRICAI-2014)*, 2014.
6. Geoffrey Chu and Peter J. Stuckey. Inter-instance nogood learning in constraint programming. In Michela Milano, editor, *Principles and Practice of Constraint Programming - 18th International Conference, CP 2012, Québec City, QC, Canada, October 8-12, 2012. Proceedings*, volume 7514 of *Lecture Notes in Computer Science*, pages 238–247. Springer, 2012.

7. G. Chu and P.J. Stuckey. A generic method for systematically identifying and exploiting dominance relations. In Michela Milano, editor, *Principles and Practice of Constraint Programming - 18th International Conference, CP 2012, Québec City, QC, Canada, October 8-12, 2012. Proceedings*, volume 7514 of *Lecture Notes in Computer Science*, pages 6–22. Springer, 2012.
8. Geoffrey Chu and Peter J. Stuckey. Nested constraint programs. In Barry O'Sullivan, editor, *Principles and Practice of Constraint Programming - 20th International Conference, CP 2014, Proceedings*, volume 8656 of *Lecture Notes in Computer Science*, pages 108–124. Springer, 2014.
9. Andreas Schutt, Geoffrey Chu, Peter J. Stuckey, and Mark Wallace. Maximizing the net-present-value for resource constrained project scheduling. In Nicolas Beldiceanu, Narendra Jussien, and Eric Pinson, editors, *Integration of AI and OR Techniques in Contraint Programming for Combinatorial Optimzation Problems - 9th International Conference, CPAIOR 2012, Nantes, France, May 28 - June1, 2012. Proceedings*, volume 7298 of *Lecture Notes in Computer Science*, pages 362–378. Springer, 2012.
10. Andreas Schutt, Thibaut Feydy, and Peter J. Stuckey. Explaining time-table-edge-finding propagation for the cumulative resource constraint. In Carla P. Gomes and Meinolf Sellmann, editors, *Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems, 10th International Conference, CPAIOR 2013, Yorktown Heights, NY, USA, May 18-22, 2013. Proceedings*, volume 7874 of *Lecture Notes in Computer Science*, pages 234–250. Springer, 2013.
11. Andreas Schutt, Thibaut Feydy, and Peter J. Stuckey. Scheduling optional tasks with explanation. In Christian Schulte, editor, *Principles and Practice of Constraint Programming - 19th International Conference, CP 2013, Uppsala, Sweden, September 16-20, 2013. Proceedings*, volume 8124 of *Lecture Notes in Computer Science*, pages 628–644. Springer, 2013.
12. Peter J. Stuckey. There are no CNF problems. In Matti Järviselo and Allen Van Gelder, editors, *Proceedings of the 16th International Conference on Theory and Applications of Satisfiability Testing*, volume 7962 of *Lecture Notes in Computer Science*, pages 19–21. Springer, 2013.
13. Peter J. Stuckey. Those who cannot remember the past are condemned to repeat it. In Christian Schulte, editor, *Principles and Practice of Constraint Programming - 19th International Conference, CP 2013, Uppsala, Sweden, September 16-20, 2013. Proceedings*, volume 8124 of *Lecture Notes in Computer Science*, pages 5–6. Springer, 2013.
14. Toby Walsh. Allocation in Practice. In Lutz Carsten and Michael Thielscher, editor. *37th Annual German Conference on AI, Stuttgart, Germany, September 22-26, 2014, Proceedings*. Lecture Notes in Computer Science, volume 8736, 2014.
15. Toby Walsh. Challenges in Resource and Cost Allocation. *29th AAAI Conference on Artificial Intelligence (AAAI-15)*, 2015.

Refereed workshop proceedings

16. Martin Damyanov Aleksandrov, Pedro Barahona, Philip Kilby, and Toby Walsh. Heuristics and policies for online pickup and delivery problems. In *Proceedings of AAAI 2013 Workshop on Combining Constraint Solving with Mining and Learning*. AAAI Press, 2013.